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955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: December 1, 1971

to: Distribution

B71 12003

from: D. A. De Graaf

subject: Ground Track Predictability for Skylab - Case 610

ABSTRACT

Insertion errors, tracking measurement errors, and random variations in drag can all cause the Skylab orbit height to be different than expected, which in turn changes the orbit period and shifts the orbit ground track in longitude. Since unexpected ground track deviations can upset the intricate plans for scheduling EREP data-taking among other Skylab activities, it is important to know the prediction accuracy.

Ground track uncertainty is shown graphically vs. prediction time for errors in semi-major axis due to insertion, measurement, and drag. Insertion error completely dominates the others throughout the mission, so much so, in fact, that pre-flight predictions of EREP field-of-view coverage will be substantially inaccurate beyond the second day of the mission.

Real time predictions based on tracking data will be good for about twenty days.

If it were decided to force the orbit to behave nominally by judicious application of RCS thrust, the insertion dispersions could be eliminated early in the SL-2 mission. Thereafter, the accumulated effect of drag variation would call for trim burns no more often than every twenty days.

(NASA-CR-124747) GROUND TRACK PREDICTABILITY FOR SKYLAB (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

For planning Earth Resources Experiment activities in the Skylab mission, both pre-flight and in real time, it is good to have an idea of how accurately the ground track can be predicted. If we examine each of the six orbital elements to see what effect a small deviation from nominal has on the orbit ground track, we find that only a, the semi-major axis, has a secular effect which produces a deviation that grows with time. All the others produce only cyclic deviations from the nominal track which are small enough to be ignored.

The parameter a affects the ground track basically by altering the orbit period, allowing the earth to rotate a different amount between spacecraft equator crossings. The orbit height also affects the rate of precession of the orbit in inertial space, but this is a very much smaller effect.

The value of a can be in error from three causes: insertion errors, measurement error, and drag unpredictability. Insertion error causes the actual trajectory to be slightly different from the pre-planned one. This error in a, maintained constant over the prediction time, produces a continuously growing error in phase angle. Measurement error has a similar effect. After the orbit is established, tracking data can be processed to determine the value of a to much better accuracy, but the small constant residual error will still cause the actual trajectory to diverge from the computed trajectory. The drag error causes the orbit to decay faster or slower than nominal, depending on random fluctuations in solar activity. This causes the value of a to diverge from the nominal decay profile even if the initial value were exactly known. To estimate the potential limits of this random variation we have kept the drag constant at the 2σ high value and 2σ low value and compared the resulting altitude decay with nominal in Figure 1. It is apparent that the whole drag decay effect is quite small and that the extra variation due to $\pm 2\sigma$ drag increases approximately linearly with time at the extra rate of about 1.3 nm in 200 days.

The nodal period of the orbit can be written as

$$\tau_N = 2\pi \sqrt{\frac{\bar{a}^3}{\mu}} \left[1 - 3J_2 \left(\frac{R_e}{\bar{a}}\right)^2 \left(\frac{7 \cos^2 i - 1}{8}\right)\right]$$

which includes the dominant perturbation of earth's oblateness. For the very small changes, Δa, that concern us, the J_2 term can be neglected in the difference equation:

$$\Delta\tau_N = {}^3/_2 \; \tau_N \frac{\Delta a}{a} \quad .$$

After M orbits, the time of arrival at the node differs from nominal by the sum or integral of $\Delta\tau_N$ over all M orbits:

$$\Delta T_M = \int_0^M {}^3/_2 \; \tau_N \frac{\Delta a}{a} \; dM \quad ,$$

where Δa is either a constant for an initial condition error, or a linear function of M reflecting drag variation. Therefore ΔT_M will increase with the first power of M for insertion, or measurement errors; and with the second power of M for drag error.

Quantitative results are plotted on log-log scales in Figure 2, showing the uncertainty in nodal arrival time vs. the number of orbits over which the prediction is made. A representative 3σ insertion error of 1. nm, a 3σ measurement error of .04 nm, and the 2σ (continuously) high drag cases are compared. These values for insertion error and measurement error were extracted from References 1 and 2.

From these curves it is clear that the trajectory variation from the pre-launch nominal will be completely dominated by the insertion error. Not until more than eight months after insertion will the drag dispersion grow as large. However, the dispersions are really quite small in magnitude. It takes 1200 revolutions, or about 83 days, for the 3σ dispersion to reach 46 min, or half the orbit period.

After the orbit is established, tracking measurements can be used to obtain a much more accurate prediction. Assuming the tracking data can be processed to determine a to the stated 3σ accuracy of .04 nm, the measurement error will dominate the orbit uncertainty for the first 165 orbits, but beyond that, drag variation will dominate.

The geographic longitude of the ascending node λ_N is directly related to the time at the ascending node due to the earth's rotation. Figure 3 shows how λ_N uncertainty depends on the same parameters. (Only the vertical scale is changed, reflecting the relation between time and longitude at the node.)

λ_N is the key parameter that defines the geographic path of the ground track for the ensuing orbit. A typical EREP experiment, S190, uses cameras with a field-of-view 86 nm across. At the equator this spans 2.23° of longitude, so it seems reasonable to require a prediction accuracy of 10% or 0.223° to ensure the view will be substantially what was expected. The insertion error curve shows this accuracy can be met only for the first 24 orbits of the mission; after that all the pre-launch predictions of ground track will be essentially worthless for describing the experiment field-of-view on each pass.

On the other hand, once the orbit is established and measured by radar, predictions of this quality can be safely made for 310 orbits (20 days). Since predictions over that span are dominated by drag error, improvements in radar quality wouldn't help.

The great difference between insertion accuracy and measurement accuracy suggests that it would be very worthwhile to try to control the orbit height by using the RCS propulsion to trim out dispersions from nominal. Since the height corrections are very small, it should be possible to attain a desired value of a to substantially the same accuracy as the radar can measure it. Thus, the orbit could be forced to nominal conditions within the first few days of SL-2. Once established, additional corrections would only be required at intervals when a drag error had caused deviations that were significant to the EREP experiments. As the curve shows, this interval would be no shorter than 310 orbits (20 days).

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D. A. De Graaf

Attachments

References

1. Saturn V/DWS Dispersion Analysis of Reference Trajectory, Part II, S. C. Krausse, et al., The Boeing Company, Report No. 5-9400-H-446, prepared for the Marshall Space Flight Center under Contract No. NAS8-5608, March 11, 1970.

2. Apollo 9 Spacecraft Operational Dispersion Analysis, Vol. IV - Navigational Error Analysis, David Dvorkin, MSC Internal Note No. 69-FM-7, Manned Spacecraft Center, Houston, Texas, January 10, 1969.

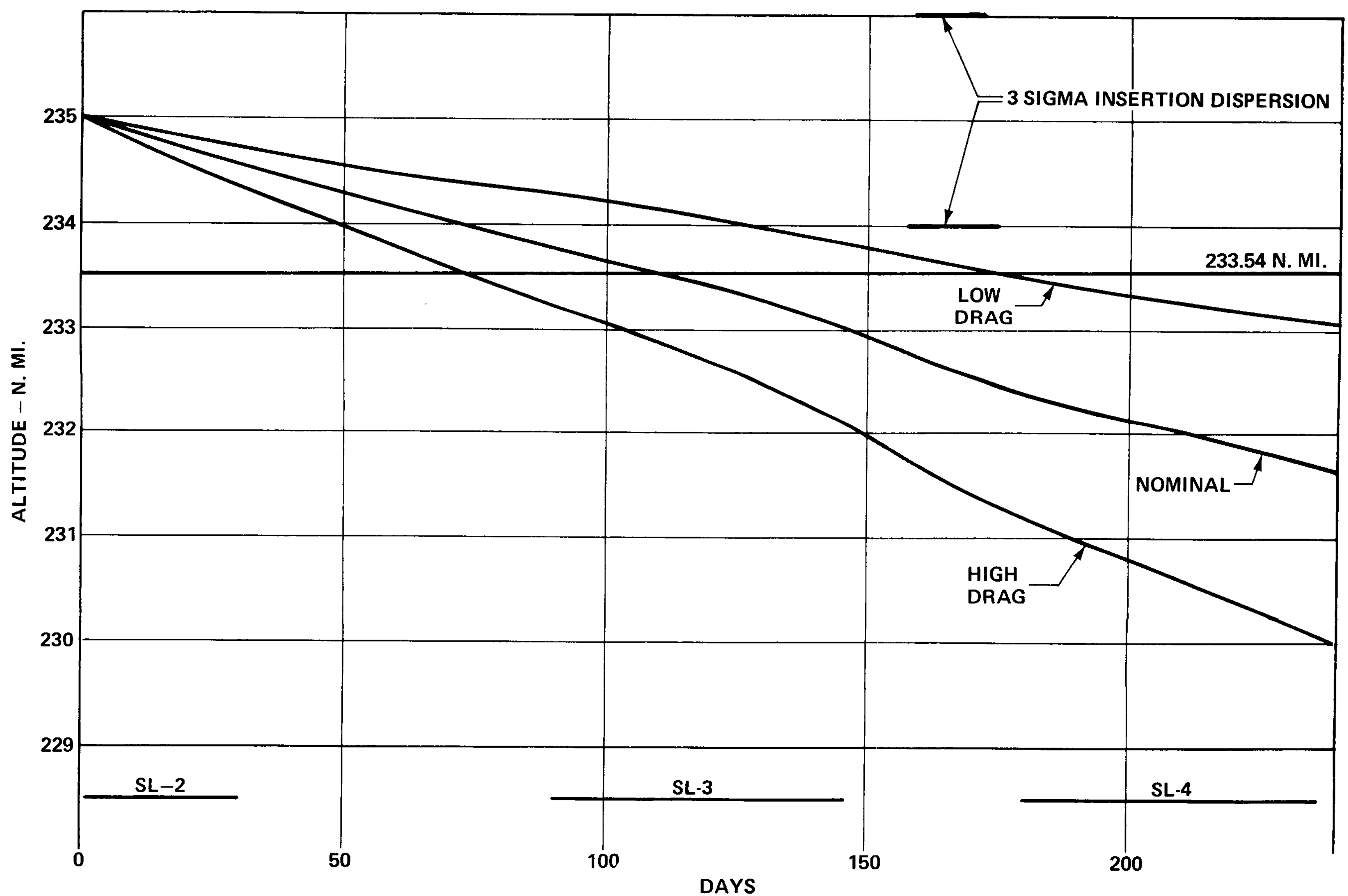

FIGURE 1 - SKYLAB CLUSTER AVERAGE ALTITUDE VS MISSION DAY

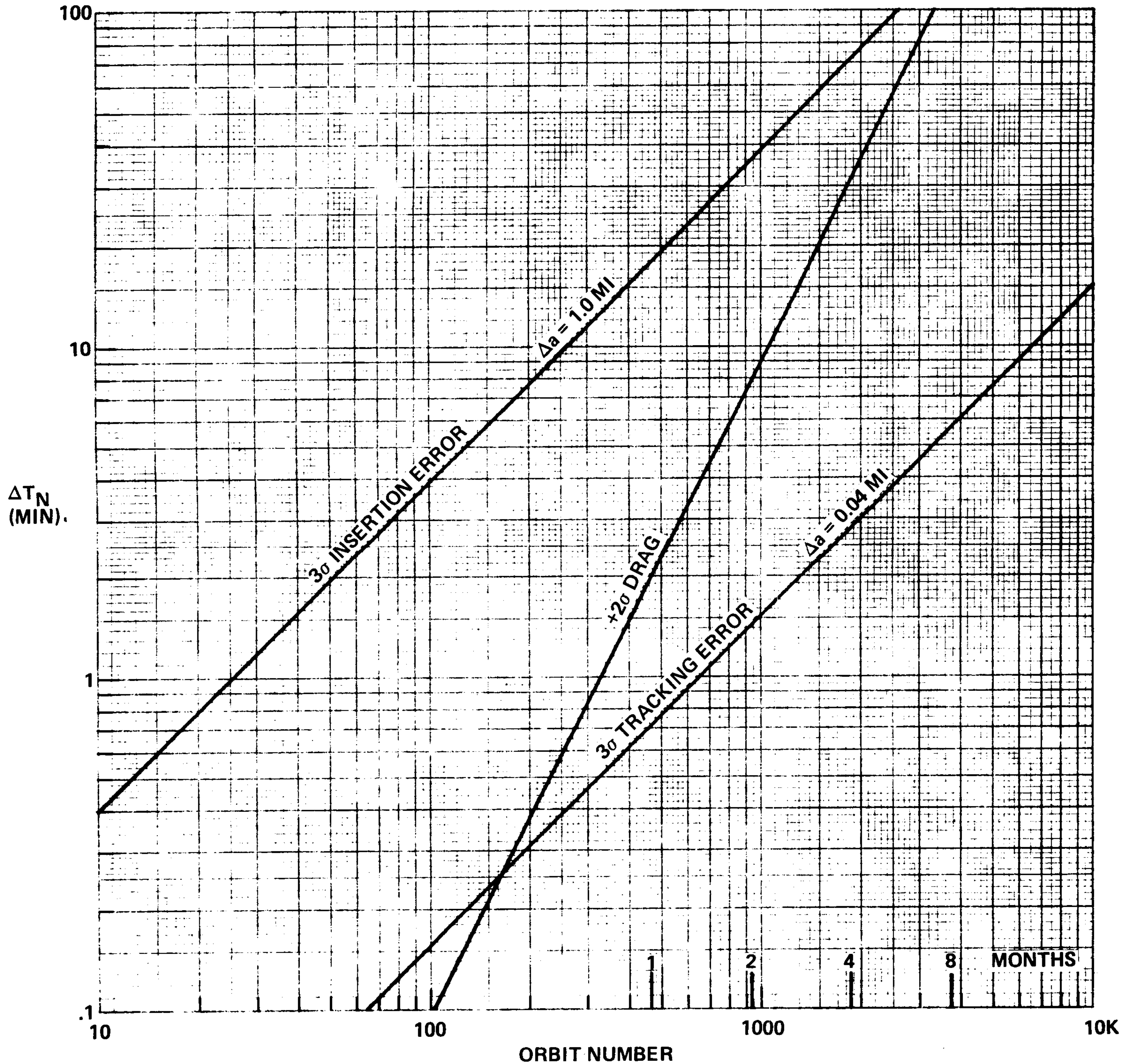

FIGURE 2 - UNCERTAINTY IN TIME AT THE NODE VS ORBIT NUMBER

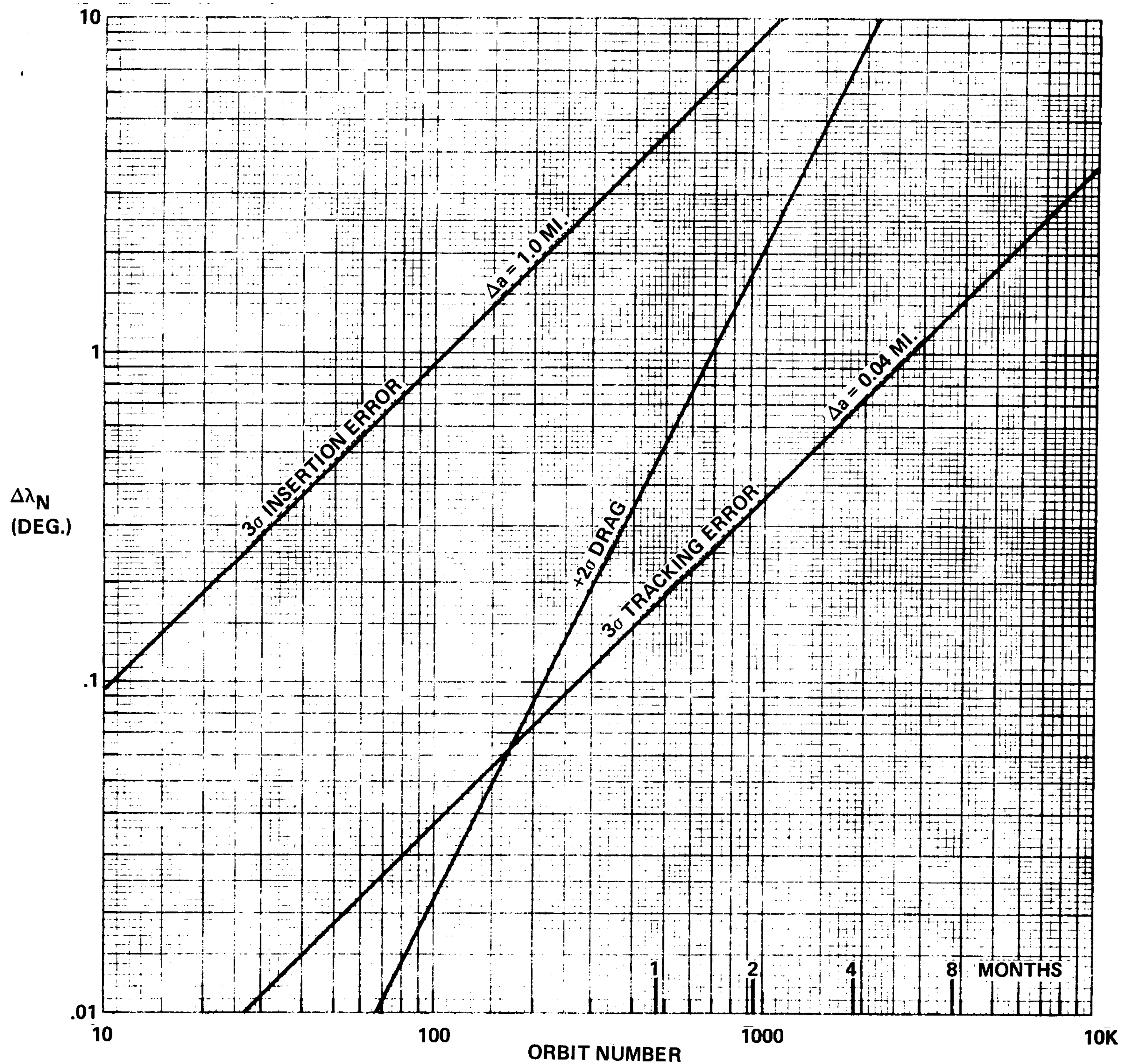

FIGURE 3 - UNCERTAINTY IN NODE LONGITUDE VS ORBIT NUMBER

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